INTRODUCTION

SR-71 aircraft operate in an exceptionally large Mach and altitude envelope, but the equivalent airspeed, angle of attack, and load factor envelope is narrow. Typical takeoff and landing airspeeds are 210 and 155 knots, respectively; climbs are at 400 to 450 KEAS, and normal supersonic cruise is from 310 to 400 KEAS. These aircraft obtain maximum cruise performance near Mach 3.2 at altitudes from 74,000 to 85,000 feet. The external configuration, air inlet system, power plant, and fuel sequencing are optimized for Mach 3.20. True airspeeds attained are near 1850 knots. For stability considerations, a three-axis stability augmentation system (SAS) is an integral part of the aircraft control system and is normally used for all flight conditions. The normal flight characteristics discussed in this section assume proper SAS operation, unless specified otherwise, and observance of limits specified in Section V.

CONFIGURATION EFFECTS

External configuration features which affect flight characteristics include the delta wing, fuselage chines and the engine nacelle location.

Delta Wing

The SR-71 has normal delta wing characteristics. There is a large increase in drag as limit angle of attack is approached. This delta wing characteristic can cause very high rates of sink to develop if the aircraft is flown too slow. Dihedral effect is positive, but diminishes at higher Mach. Roll damping is relatively low over the entire speed range and lateral-directional qualities are poor with SAS off.

The outboard portion of the wing's leading edge has negative conical camber. This moves the center of lift inboard to relieve loading on the nacelle carry-through structure. It also improves the maximum lift characteristics of the outboard wing at high angles of attack, and enhances crosswind landing capability.

Chines

The SR-71 has a blended forward wing (chine) which extends from the fuselage nose to the wing leading edge. This chined forebody is approximately 40% of the aircraft length. The chines improve directional stability with increasing angle of attack at all speeds. However, their primary purpose is to provide a substantial portion of the total lift at high supersonic speeds and eliminate a need for canard surfaces or special nose-up trimming devices.

A large rearward shift in the aerodynamic center of lift occurs when the aircraft transitions from subsonic to supersonic flight. Without chines, the center of lift would shift aft while in the transonic region and remain between 40% to 45% mean aerodynamic chord (MAC) at all speeds above Mach 1.4. A large elevon deflection would be required for trimming, and the resultant drag would be unacceptable. A similar shift of the aerodynamic center occurs at transonic speeds with chines, but the initial displacement is to a position between 35% to 40% MAC. As Mach increases, the center of lift moves forward until a position slightly aft of 25% MAC is reached at the design speed. The result is that the static stability margin is maintained at desirable levels and trim drag due to elevon position is reduced to a minimum at design speed. The SAS provides satisfactory handling qualities.

Automatic fuel tank sequencing shifts the c.g. aft to approximately 25% MAC while the fuel in tank 1 is being reduced to the right-hand shut-off level. This normally occurs during acceleration to supersonic cruise and conforms with the aft shift of the aerodynamic center.

NOTE

> Because of chine effectiveness, c.g. must be moved forward of 25% if design speed is exceeded. Refer to Center of Gravity, Section V.

Nacelle Location

The mid-span location of the engines minimizes drag and interference effects of the fuselage. The inboard cant and droop of the nacelles gives maximum pressure recovery at normal angle of attack for high altitude supersonic cruise. However, the nacelle location makes the aircraft sensitive to asymmetric thrust conditions. During afterburner cruise, match fuel flows to minimize thrust differences. During subsonic cruise, match engine EGT's and nozzle positions (instead of fuel flows) since heat sink system requirements are an appreciable portion of indicated fuel flows during non-afterburning operation.

ANGLE OF ATTACK

Angle of attack indications range from 8° to 12° for takeoff (depending on weight and procedure used), 3° to 5° during climb, and 4° to 7° during cruise. Angle of attack at optimum supersonic cruise altitudes is about 5° to 6° for all gross weights. The indication is approximately 10.5° during final approach at recommended airspeeds; although, during landing approach in gusty conditions, the indication will oscillate. The indicated angle of attack is approximately equal to the true angle of attack.

Definitions of Longitudinal Reference Angles

Angle of Attack

Angle of attack is the angle between the wing chord plane at the mean aerodynamic chord and the relative wind. When not turning, this angle is also equal to the difference between the pitch angle of the fuselage reference line (FRL) and the airplane flight path (measured relative to horizontal) minus 1.2° (the wing angle of incidence relative to the FRL is 1.2° negative). See Figure 6-1. The pilot's instrument provides wing angle of attack.

Relative Wind

Relative wind is the apparent speed and direction of air passing the aircraft parallel to the aircraft flight path. The speed of the relative wind is equal to the airplane's true airspeed.

Flight Path Angle

The flight path angle is the angle between the relative wind and the horizontal plane. It can be determined from true airspeed and rate of climb or descent.

Deck Angle or Pitch Angle

Pitch angle (deck angle) is the angle between the fuselage reference line and horizontal. It is associated with, but not necessarily the same as, the pitch attitude indication. The attitude instruments would indicate true pitch angle if set at 0° with the airplane FRL level (for example, while on the ground) and not reset, and if no precession error occurs in pitch.

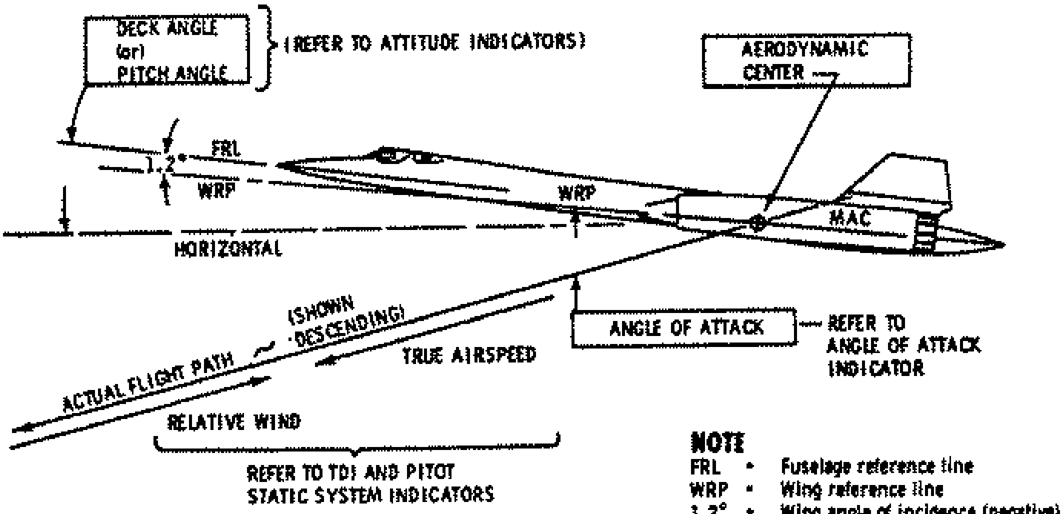
Angle of Attack As A Flight Parameter

Lift is a function of airspeed and angle of attack. Assuming weight does not change appreciably, the lift required for straight and level flight is constant. To maintain straight and level flight: if KEAS increase, alpha must decrease; and if KEAS decrease, alpha must increase. This direct relationship of angle of attack and KEAS with lift allows angle of attack to be used in place of airspeed, if necessary. If the airspeed systems malfunction and angle of attack remains, angle of attack can be held constant to hold relatively constant equivalent airspeed conditions.

HIGH ANGLE OF ATTACK CONDITIONS

In-flight minimum airspeed restrictions and maximum angle of attack limits are imposed to prevent approach to pitch-up conditions.

LONGITUDINAL REFERENCE ANGLES



NOTE
FRL • Fuselage reference line
WRP • Wing reference line
1.2° • Wing angle of incidence (negative)
MAC • Mean aerodynamic chord, or reference chord

Figure 6-1

There is no stall in the classic sense where an abrupt loss in lift would occur at a critical angle of attack. (See Figure 6-2, Lift vs Angle of Attack.) Instead, a nose-up pitching moment develops as angle of attack increases, which becomes uncontrollable (even with full nose-down elevon) as the critical angle of attack boundary is reached. (See Figure 6-3, Subsonic Critical Angle of Attack Boundary.) An uncontrollable pitch-up will not occur until after limit angle of attack as given in Section V is reached. The SAS will tend to maintain apparent stability about all three axes until pitch-up occurs, then aircraft control is lost with little or no warning.

WARNING

Reduce angle of attack and adjust attitude nose-down if a high angle of attack warning occurs or if an alpha limit is approached. Do not confuse angle of attack with flight attitude. A dangerously high angle of attack can be reached while flight attitude is relatively level if the aircraft is descending or sinking. See Figure 6-1.

WARNING

Nose-up pitch trim above zero indication reduces down elevon authority. If full forward stick is not sufficient to control angle of attack and pitch rate, <u>trim nose down</u>.

At subsonic speeds, engine stalls may occur when at angles of attack above 10°, with more susceptibility existing while at airspeeds below 300 KEAS and altitudes above 25,000 feet. In such a condition, loss of thrust due to the stalls requires that angle of attack be reduced immediately and KEAS increased if pitch-up is to be avoided.

Note that the critical angle of attack for pitch-up is approximately 18° when subsonic and at the aft c.g. limit of 22%. The critical angle of attack is slightly higher if at a more forward c.g. The angle is less when supersonic, and varies with Mach. Center of gravity aft of the limit materially reduces the margin between the limit alpha and the critical angle of attack for pitch-up. When near the limit angle of attack, recovery from a rapid nose-up pitch rate may not be possible.

WING LIFT VS ANGLE OF ATTACK

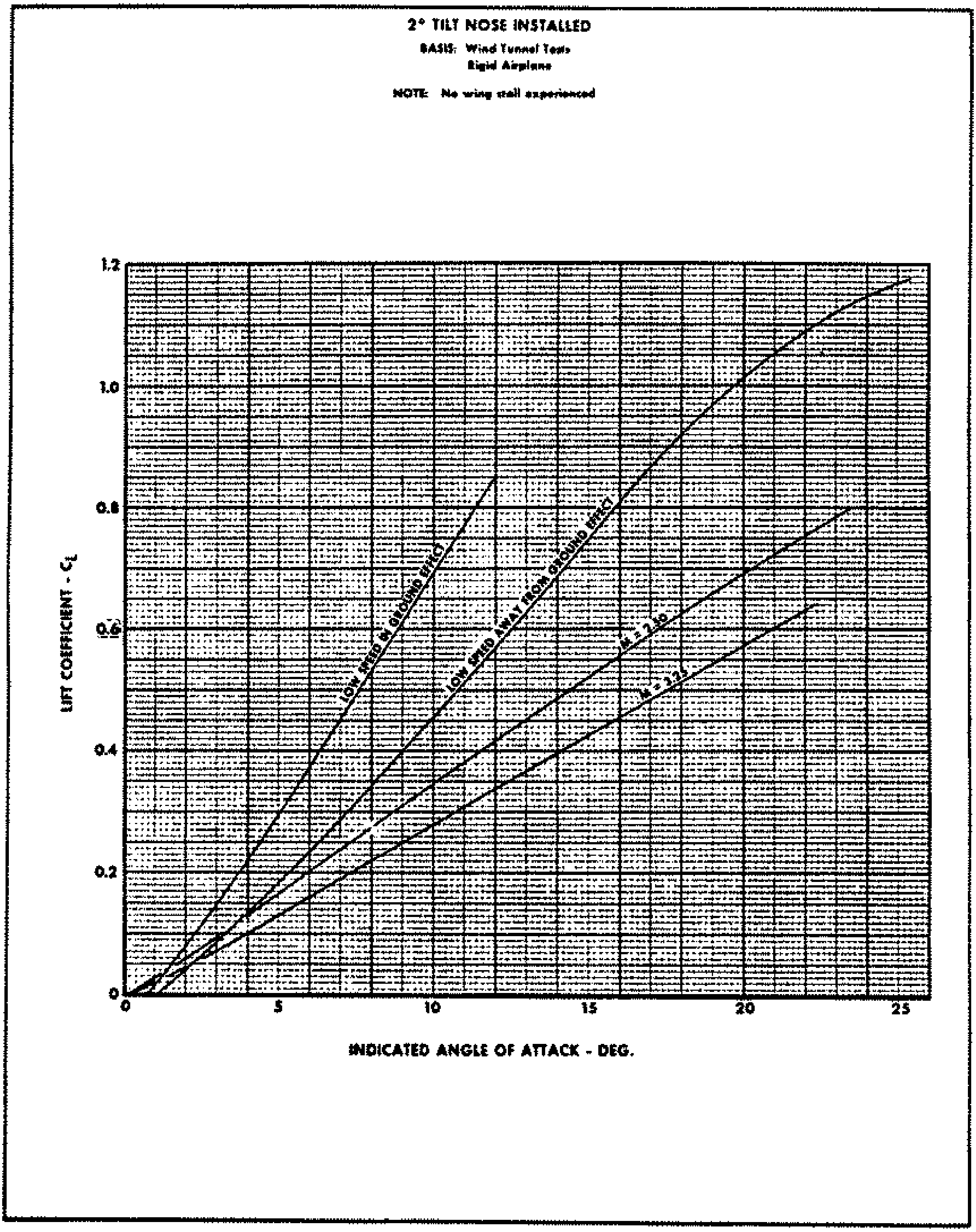
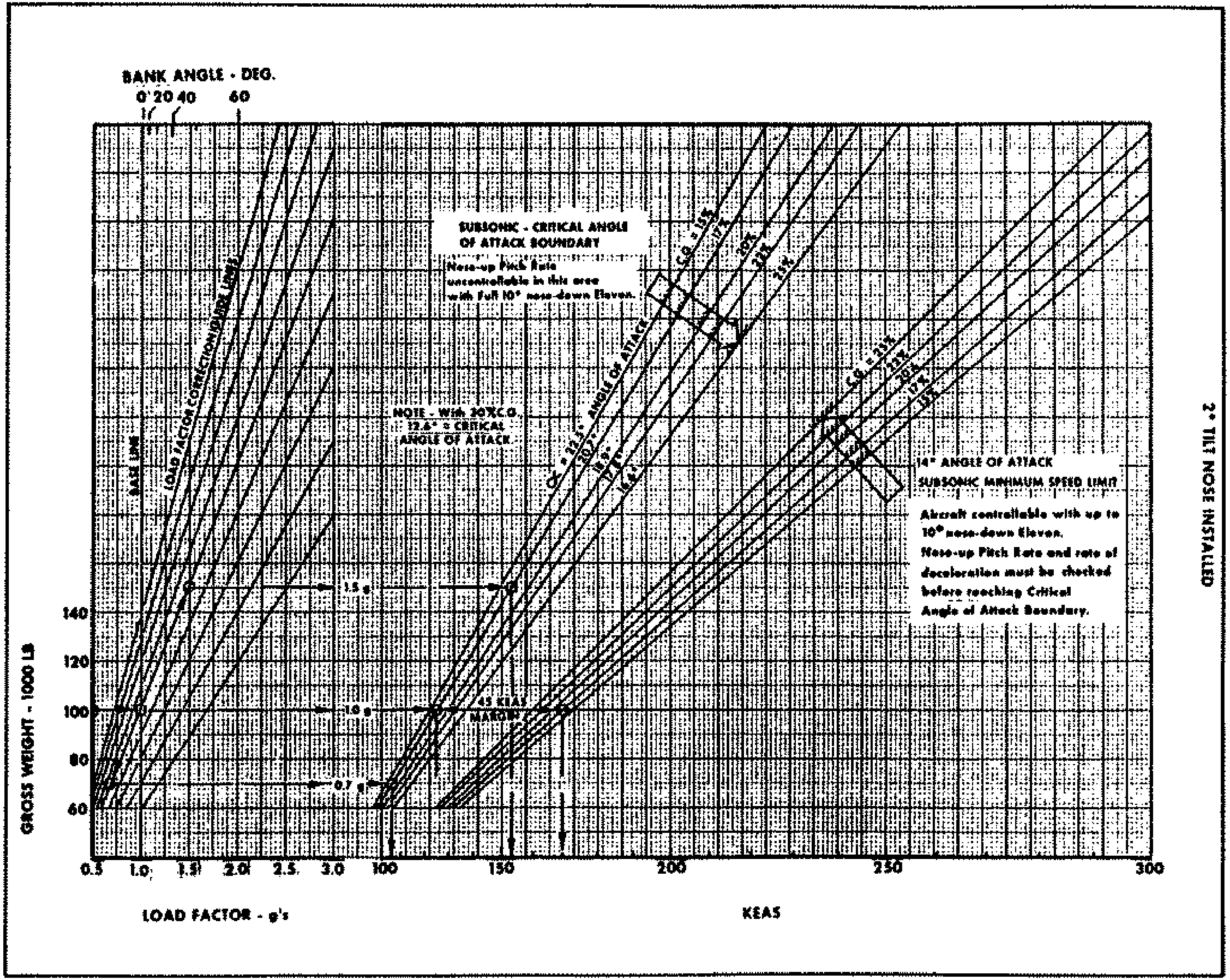


Figure 6-2

SUBSONIC - CRITICAL ANGLE OF ATTACK BOUNDARY



SUBSONIC - CRITICAL ANGLE OF ATTACK BOUNDARY

Nose-up Pitch Rate uncontrollable in this area with Full 10° nose-down Elevon.

NOTE - With 30% C.G. 12.6° = CRITICAL ANGLE OF ATTACK.

14° ANGLE OF ATTACK SUBSONIC MINIMUM SPEED LIMIT

Aircraft controllable with up to 10° nose-down Elevon. Nose-up Pitch Rate and rate of deceleration must be checked before reaching Critical Angle of Attack Boundary.

Figure 6-3

WARNING

> Uncontrollable pitch-up occurs at the critical angle of attack boundary. Recovery from this condition is extremely unlikely. Attempted recovery must not be continued to the point where insufficient altitude for recovery or ejection exists.

Pitch rates which accompany increasing angles of attack must be checked and load factor relieved at a sufficient rate to increase airspeed when the critical angle of attack boundary is approached. Recovery should be controlled by cross-referencing pitch rate, angle of attack, airspeed, and attitude. Airspeed must be allowed to increase, but not to extremes, so that recovery load factors will neither cause limit angle of attack to recur or impose loads beyond allowable values. During subsonic recovery, use cruise angle of attack as the basic reference while accelerating to 300-350 KIAS. When near limit Mach number, it may be necessary to reduce power and/or increase drag while recovering so that limit Mach number is not exceeded while airspeed is increasing.

WARNING

> Extreme caution is necessary while turning at altitudes above those for optimum supersonic cruise. The angle of attack may exceed 7° to 8°, and any transients caused by unstarts, increased bank angles, etc., may lead to pitch-up.

SPINS

Intentional spins are prohibited. The following technique is suggested if an inadvertent spin occurs; however, ejection may be the best course of action because spin recovery has not been demonstrated and is considered extremely unlikely. At the pilot's discretion:

1. Center controls, disengage surface limiters, and determine the direction of rotation from the turn indicator.
2. Apply forward stick and full roll control into the direction of spin (into the turn needle) as the nose drops.
3. Apply opposite rudder to stop rotation.
4. Center the rudder and roll control as rotation stops.
5. Start pull-out at 300 to 350 KIAS.
6. If possible, avoid exceeding 450 KIAS and limit load factor during recovery.

WARNING

> If uncontrollable, eject at least 15,000 feet above the terrain.

STABILITY CHARACTERISTICS

The augmented (SAS on) dynamic stability is positive and dynamic damping is essentially deadbeat. Static stability is positive when operating within the c.g. and angle of attack limits. Positive static stability continues when c.g. is somewhat aft of the limit while at intermediate supersonic speeds (from Mach 1.2 to at least Mach 2.6.) However, if the aft c.g. limit is violated while near the design cruise Mach number, a static instability in pitch may result. If pitch rates are then generated and not arrested within the angle of attack limit, a pitch-up can develop and result in structural failure of the aircraft.

EFFECTS OF C.G. LOCATION

To fully understand the effects of center of gravity location on longitudinal flight characteristics, it is necessary to be familiar with the following terms:

Static Stability

Static stability is the initial tendency of an airplane to return to "one-g" flight after being disturbed from its trimmed attitude. An example of a statically stable system is shown in Figure 6-4. In the example, if the angle of attack is increased by an upward gust or outside disturbance, the increased lift created causes a nose-down moment about the center of gravity which tends to return the airplane to its trimmed angle of attack.

Static Margin

Static margin is the distance between the aerodynamic center of the aircraft and its center of gravity. Static margin determines the degree of static stability of an aircraft. This margin can be changed by shifting the center of gravity or by varying the airspeed to shift the aerodynamic center. As static margin increases, small disturbances from the trimmed attitude of the aircraft result in larger restoring moments. As static margin decreases, stability of the aircraft decreases accordingly to a point where an outside disturbance could cause a divergence (either up or down) that the pilot could not control.

Dynamic Stability

Dynamic stability is the tendency of an airplane to overcome a disturbance from its trimmed condition, dampen out the resulting oscillations, and return to its original angle of attack. The degree of dynamic stability is indicated by the number of cycles (of decreasing amplitude) required to dampen the oscillations. For a system to be dynamically stable, it <u>must</u> be statically stable. Examples of a statically stable system depicting dynamic stability, dynamic neutral stability, and dynamic instability are shown in Figure 6-5. An example of a statically unstable system showing pure divergence or loss of control is also shown.

EXAMPLE OF STATICALLY STABLE SYSTEM

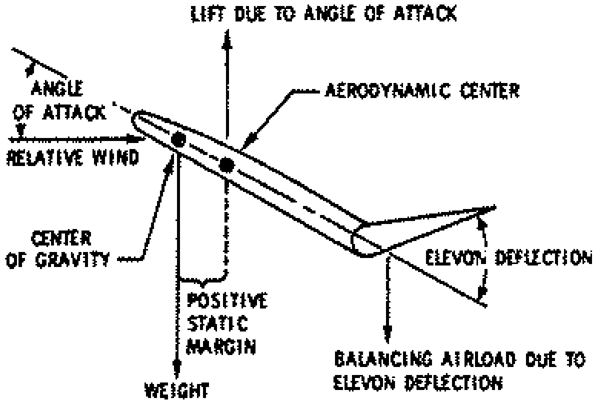


Figure 6-4

Effect of C.G. On Control Characteristics

The relation of center of gravity and aerodynamic center location (static margin) determines the static stability of the airplane. If the center of gravity is forward of the aerodynamic center, the airplane has static stability. Moving the c.g. further forward increases static stability. Moving the c.g. aft decreases static margin and decreases static stability accordingly. Static instability results if the center of gravity is aft of the aerodynamic center. SAS operation tends to overcome a small degree of static instability; however, a disturbance could cause the airplane to diverge beyond pilot control, even with full application of control stick and pitch trim.

NOTE

As the center of gravity moves aft and static margin decreases, less elevon deflection is required to maneuver. Neutral stability is approached if the aft c.g. limit is exceeded.

EXAMPLES OF ANGLE OF ATTACK VS TIME WITH VARIOUS DYNAMIC STABILITY CONDITIONS

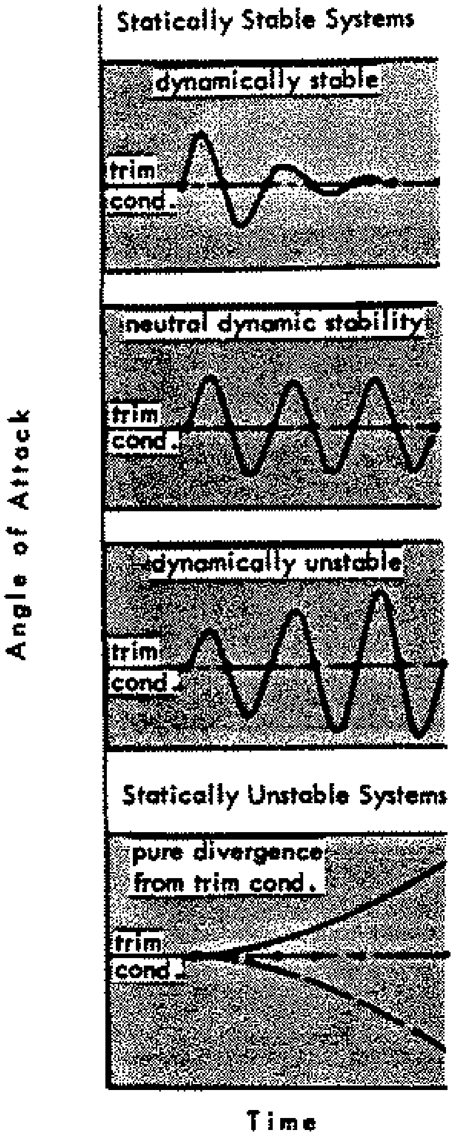


Figure 6-5

The supersonic aft center of gravity limit insures acceptable SAS-on stability and handling qualities commensurate with performance objectives. At forward center of gravity locations, large elevon deflections are required to trim and maneuver the airplane. The center of gravity should be maintained near the aft center of gravity limit, when range is a consideration, to mimimize elevon deflection and reduce drag. Normally, this is accomplished automatically by the fuel sequencing system.

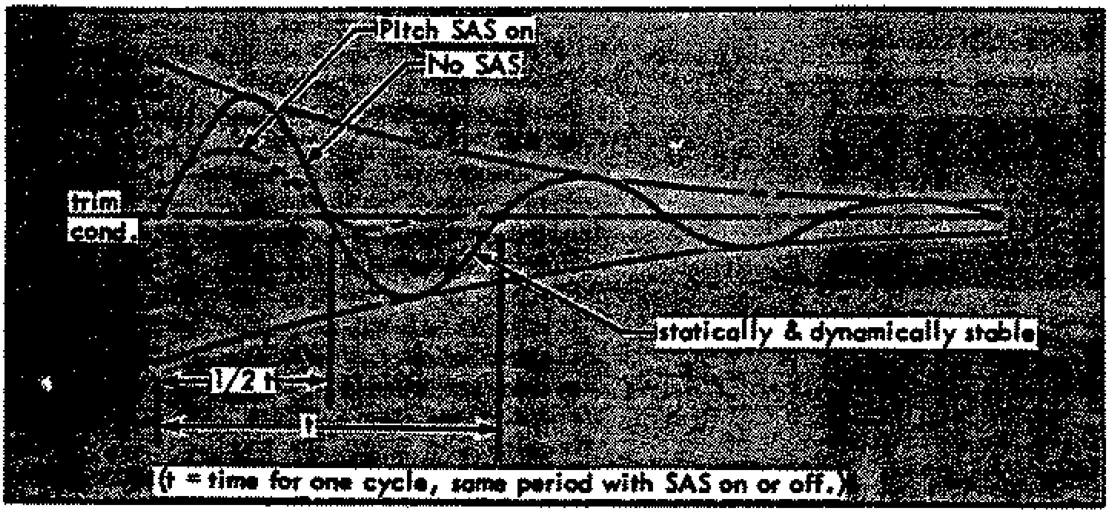
Short Period Longitudinal Oscillation

Short period longitudinal oscillation means the relatively short-time pitching motions of an airplane after being disturbed in pitch. With the pitch SAS on, the longitudinal short period motion is so heavily damped that the pilot is not aware of any oscillatory motion. With the pitch SAS turned off, however, a disturbance of the aircraft results in oscillatory motion (nose-up, nose-down, nose-up) that persists for several cycles before the motion subsides (damps out). The effect of pitch SAS and center of gravity position on this motion is illustrated by Figure 6-6. Note that moving the center of gravity forward shortens the time for each cycle of motion, and moving the center of gravity aft increases the time for each cycle. If the center of gravity is moved progressively farther aft, the static margin approaches zero and the time-per-cycle for the short period oscillation becomes increasingly longer. At zero static margin (center of gravity behind the aft limit), SAS operation tends to dampen the oscillations and mask the condition. If the center of gravity is moved still farther aft (to a negative static margin) the SAS becomes ineffective and the airplane may exhibit dynamic instability without damping. With extreme aft c.g. position, the aircraft will exhibit a pure divergence; that is, the airplane will continue to pitch in the same direction at an increasing rate upon being disturbed from trim. The pilot can correct pitch motion using elevon control if the amount of instability (negative static margin) is small and if he applies correction control as soon as he recognizes any divergent pitching motion. If he allows the motions to become large, however, the pitching moment will exceed the corrective moment that he can supply with elevon and loss of control results.

EXAMPLES OF ANGLE OF ATTACK VS TIME

**Effect of Pitch SAS and
C.G. Position on Damping With
Longitudinal Short Period Oscillations**

Effect of Pitch SAS on Damping



Effect of C.G. on Damping

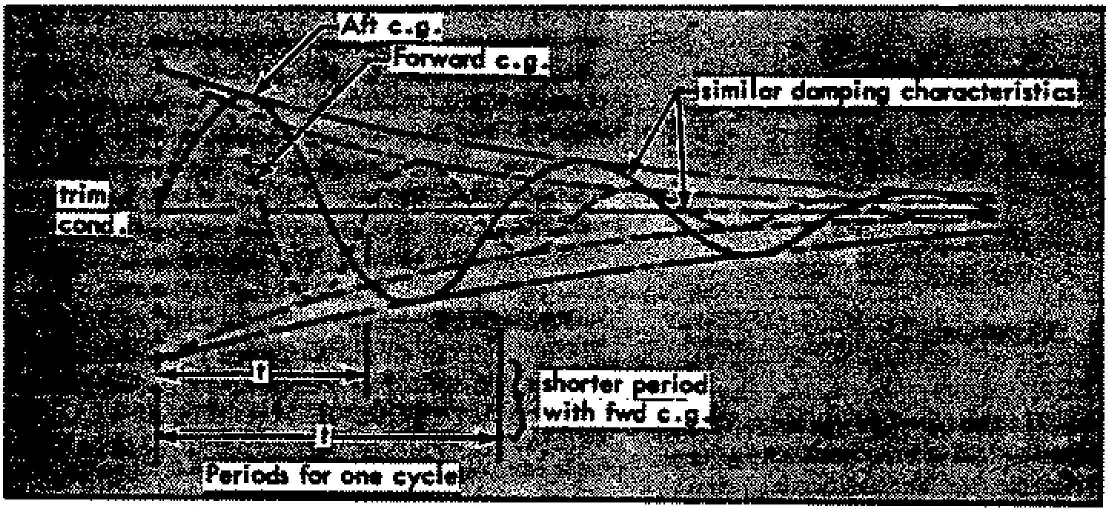


Figure 6-6

Stability With SAS Off

Aircraft controllability without stability augmentation has been demonstrated to Mach 3.20. SAS off flight tests have also demonstrated controllability in climb and descent, during inlet unstart at Mach 2.8 and 430 KEAS, during unstart and engine flameout at Mach 2.5, and during twenty degree bank turns in heavy turbulence at low supersonic and transonic Mach numbers. However, control with SAS off is sensitive and control movement should be kept to the necessary minimum. Thrust asymmetry should be minimized, particularly at high Mach. Sustained cruise or maneuvering without pitch and yaw SAS is not recommended near design speed. Refer to Stability Augmentation System, Section III.

Pitch Stability at High Speeds

At cruise Mach, the pitch stability is only slightly positive and disturbances are only lightly damped. Sudden loss of all pitch SAS while maneuvering causes a pitch transient that momentarily increases the load factor for the same stick position.

Yaw Stability

SAS-off yaw stability varies from positive to very slowly divergent. Response of the automatic air inlet system to yaw oscillation has a pronounced effect on directional motion. Unless controlled by the pilot, phasing of the spikes and forward bypass doors may either drive or damp the yaw oscillations.

Single-Engine Operation - Low Speeds

The yawing moment from asymmetric thrust is large if an engine fails just after takeoff or a single-engine go-around is necessary. Approximately 2/3 to full rudder deflection and 10 degrees (or more) bank into the good engine is necessary to maintain control immediately after loss of power. Drag can then be minimized by reducing pedal force and trimming to 7° to 9° rudder position indication, while using bank and sideslip toward the operating engine to maintain the desired flight path. The SAS automatically responds with corrective control at the time of engine failure or go-around power application, and its response rate is faster than pilot reaction time. However, rudder control follow-up by the pilot is necessary as the yaw SAS authority is limited to 8 degrees rudder deflection. The SAS continues to apply rudder deflection as long as a sideslip is maintained, but this deflection is not indicated by pedal position or by the rudder trim indicator.

Single-Engine Operation - Subsonic Speeds

The rudder deflection required during single-engine operation decreases as airspeed increases. During single-engine cruise at 0.5 to 0.85 Mach number, the aircraft can maintain course with surface limiters engaged. Optimum rudder deflections are maintained by the SAS without using rudder trim when bank and sideslip toward the operating engine are used to maintain course. The bank angles required approach 10°.

Single-Engine Operation - High Speeds

Above Mach 2.8, engine failure or inlet unstart may require yaw axis stability augmentation to avoid excessive sideslip and bank angles which could cause the other inlet to unstart. Inlet unstarts while at 450 KEAS and maximum power are quite severe. In these cases, unassisted pilot reaction is too slow to provide all the control immediately required. Pilot follow-up is necessary after the initial SAS corrections.

NOTE

> Before retarding the throttle to shutdown an engine, be careful to properly identify the side with the malfunction. There have been cases where an operating engine was shutdown.

NORMAL OPERATING CHARACTERISTICS

See Appendix I for performance information.

TAKEOFF

The aircraft accelerates rapidly to rotation speed once maximum thrust is set during takeoff. The nosewheel can be lifted 50 to 60 knots below takeoff speed, but this is not advised because the drag that is created decreases the acceleration and extends the takeoff run. With zero degrees pitch trim, a stick force of approximately 25 pounds is required to lift the nosewheel at rotation speed. Stick force must be relaxed during rotation to check the nose-up pitch rate. Forward stick may be necessary if a high rate of rotation is developed or if c.g. is aft of 22%. During maximum performance takeoffs, speed and attitude must be monitored carefully to avoid overrotating and striking the tail.

CLIMB

Normal climbs to supersonic cruise speeds involve three phases of operation: a subsonic climb, a transonic acceleration to the supersonic climb schedule, and a supersonic climbing acceleration. Subsonic climb is normal except that a light airframe buffet may be felt near 0.9 Mach number as airflow conditions near the tertiary doors and ejector flap areas change.

Transonic Operation

A Mach jump on the TDI occurs between Mach 0.98 and 1.03 during transition to the supersonic climb schedule. There is an area of decreased excess thrust from Mach 1.05 to Mach 1.15. A descent technique is used to improve acceleration through this speed range. The transition should be made without other maneuvering, if possible, as even shallow turns increase drag sufficiently to decrease acceleration and increase fuel consumption considerably. A noticeable increase in acceleration occurs after passing Mach 1.15. The pull-up to establish climb attitude should be started in sufficient time to prevent overshooting climb speed.

Supersonic Operation

The supersonic climb is initiated when climb airspeed is established at approximately 30,000 feet. Maintain the schedule accurately to achieve best climb performance. Avoid speeds above the climb schedule because limit airspeed can be inadvertently approached quickly.

Pitch Axis Stability In Climb

The aircraft does not respond immediately to small pitch commands. This characteristic makes precise airspeed control difficult. If significant overspeed occurs, reduce power until climb speed can be reestablished rather than pull up sharply and impose load factors.

Pitch Trim

A continual variation in nose-up trim is required during the acceleration to cruise speed, with the 400 KEAS schedule requiring more trim than the normal 450 KEAS schedule. The variation of elevon angle and pitch trim indication for the trimmed condition is illustrated by Figure 6-7 for c.g. positions of 22% and 25%. The figure also shows the variation of trim required with airspeed and the effect of weight decrease during cruise when operating near the aft c.g. limits.

Inlet Operation

Occasional periods of inlet roughness may be encountered between Mach 2.5 and 2.8. It may also be encountered at climb speeds above Mach 3.0 if the forward bypass is hard closed. The roughness normally diminishes at cruising altitudes with equivalent airspeed reduced from the climb speed schedule. However, during cold operation, some roughness may continue if the forward bypass is hard closed (i.e., no modulation of the bypass position occurs) so that the inlet normal shock is positioned aft of the desired location.

Level Off

Ideally, the transition to cruise altitude and speed would be accomplished at constant Mach number with power being reduced upon reaching the initial cruise altitude. In practice, however, this usually results in a pronounced altitude overshoot and subsequent difficulty in stabilizing at the desired cruise condition. The following describes three distinct level off situations.

Cruise Mach and Altitude Attained Simultaneously

For the maximum range cruise profile, the initial cruising altitude is close to the altitude at which the cruise Mach is attained using the normal climb procedure. Stabilization at the desired altitude is expedited by reducing power to approximately 3/4 of the afterburner throttle range and by decreasing the climb angle slightly when 0.10 to 0.05 Mach below the desired cruise speed. Then adjust pitch attitude so that Mach increases slowly to the desired value, while the rate of climb decreases to arrive at the cruise Mach and altitude simultaneously. At the desired cruise speed and altitude, reduce power to the estimated initial fuel flow setting, and make small adjustments in both pitch attitude and power setting until cruise is stabilized.

Intermediate to High Altitude Cruise

When the initial cruise altitude is above the altitude at which cruise Mach is attained using normal climb procedure, use a constant Mach climb to cruise altitude. Increase the climb angle to decrease the rate of acceleration when 0.10 to 0.05 Mach below the desired cruise Mach and continue climbing toward the desired altitude. If acceleration rate is still excessive when approaching the desired speed, momentarily retard the throttles slightly to break the rate. With Mach stable, begin reducing climb angle when approximately 1000 to 2000 feet below the desired level-off altitude. Reduce power to maintain Mach, and slowly reduce the rate of climb as the desired cruise altitude is reached. Maintain Mach by power adjustments. Make small adjustments in pitch attitude and power setting until stabilized at cruise.

Level Off from Reduced KEAS Climb

Level-off altitude may be reached before the desired Mach is attained when climbing at 400 KEAS prior to cruise at 2.8 or 3.0 Mach. In this case (when airspeeds above 400 KEAS are permissible) reduce the climb angle to allow a gradual transition to level flight when approximately 1000 to 2000 feet below the level-off altitude. Mach and airspeed will increase more rapidly than during the previous portion of the climb. When approximately 0.03 Mach below the desired cruise speed, retard the throttles to the estimated initial fuel flow setting. Make small adjustments in pitch attitude and power setting to stabilize at the cruise condition. Mach number is quite responsive to throttle adjustment.

CRUISE

Supersonic cruising requires an awareness of high altitude techniques.

Types of Cruise Profiles

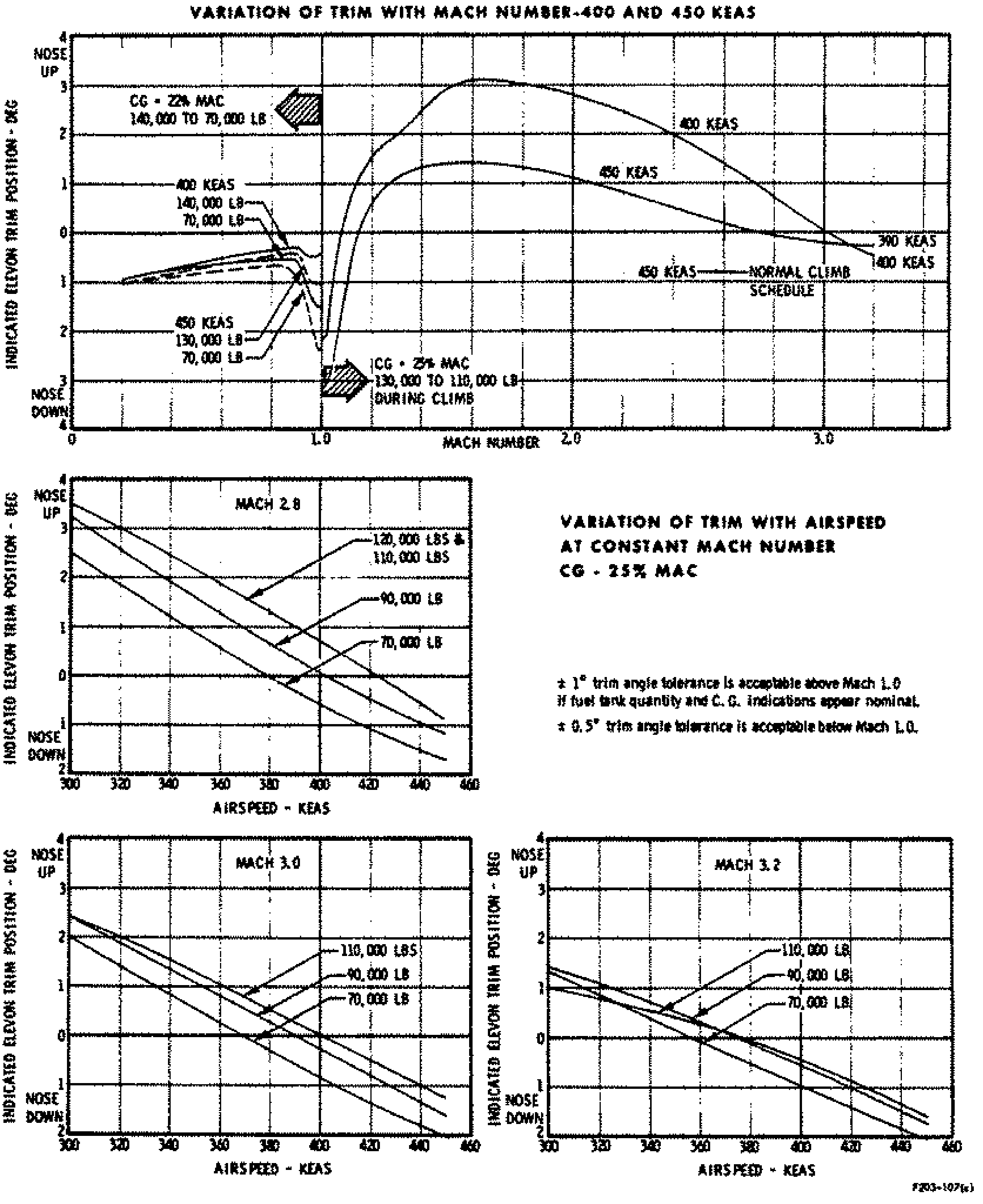
Cruise profile parameters are: desired Mach, aircraft weight (fuel remaining), and ambient temperature (CIT). The following definitions categorize several types of profiles.

a. Minimum afterburner cruise - This profile yields the lowest cruise altitude for the Mach scheduled, and usually results in less than maximum range.

b. Maximum range (optimum) cruise - This profile yields maximum range for the Mach specified. Power settings used are in the lower portion of the afterburner range.

c. Intermediate altitude cruise - This profile yields altitude schedules below the maximum altitude cruise profile, but

CHARACTERISTIC PITCH TRIM INDICATIONS



VARIATION OF TRIM WITH MACH NUMBER-400 AND 450 KEAS

VARIATION OF TRIM WITH AIRSPEED AT CONSTANT MACH NUMBER CG - 25% MAC

± 1° trim angle tolerance is acceptable above Mach 1.0 if fuel tank quantity and C.G. indications appear nominal.

± 0.5° trim angle tolerance is acceptable below Mach 1.0.

Figure 6-7

above the maximum range profile. Specific range is less than optimum, but reasonably efficient.

d. Maximum altitude cruise - This profile results in altitudes approximately 1000 feet below the maximum afterburner ceiling for the Mach specified.

e. Maximum afterburner ceiling - This profile requires continuous operation at maximum afterburner and the Mach specified.

These profiles employ a cruise climb that requires a gradual but continuous increase in altitude as fuel is consumed. As altitude increases during constant Mach cruise, KEAS decreases. For a given profile, gross weight and ambient temperature (ambient temperature and Mach influence CIT) determine the desired altitude for cruise at constant Mach number.

NOTE

> Do not allow airspeed to decrease below 310 KEAS in cruise climb. See Limit Speed and Altitude Envelope, Section V.

Refer to Figure 6-8 for a summary of maximum range and ceiling altitudes for various Mach numbers, gross weights, and ambient temperatures.

Mach, KEAS, Altitude Relationship

The selection of values for any two of the Mach, KEAS, or altitude variables automatically defines the value of the third, regardless of ambient temperature. For instance, if cruise is scheduled for Mach 3.0 and the desired initial cruise altitude is 72,000 feet, the KEAS must be 396 knots.

Effects of Changing Air Temperatures

Because of the high true airspeed at cruise, ambient air temperature may change abruptly as different air masses are encountered. Initially, if a constant altitude is maintained, flight into a warmer air mass will cause a decrease in Mach and KEAS, and the true airspeed (TAS) and compressor inlet temperature (CIT) will remain constant. A higher TAS and CIT will result as the desired Mach is reestablished. The opposite would occur as a result of flying into a colder air mass. New cruise altitudes or speeds may be required to compensate for effects of variations in ambient air temperature.

Effect Of Mach Number

For any given gross weight and ambient temperature, the altitudes for maximum range and maximum altitude cruise profiles increase with Mach. This increase is approximately 1000 feet per 0.05 Mach number. A related characteristic is that if Mach increases slightly above that desired and the throttles are not retarded, excess thrust increases. It is easy to exceed target Mach inadvertently.

MAXIMUM RANGE (OPTIMUM) CRUISE-PROFILE

At high Mach, the maximum range (optimum) profile is a continuous cruise climb at substantially constant angle of attack with the throttles in the afterburner range (approximately 1/3 forward of the minimum afterburner stop). Relatively high KEAS are required when at heavy weight. It may be necessary to fly this profile at a constant altitude for a short period, slightly higher than the altitude for best specific range, to maintain KEAS at or below the KEAS bleed schedule. In this case, the initial cruise altitude remains above the optimum until gross weight is reduced sufficiently to fly the cruise climb profile.

NORMAL AND STEEP TURNS

Constant altitude turns of up to 35° of bank can normally be made at optimum cruise altitudes by increasing thrust. Angle of attack and required fuel flow increase approximately in proportion to load factor. It is more desirable from an operational standpoint to make constant altitude turns

MAXIMUM RANGE AND CEILING ALTITUDES

2° TILTED NOSE C.G. AT 25% MAC K ENGINES

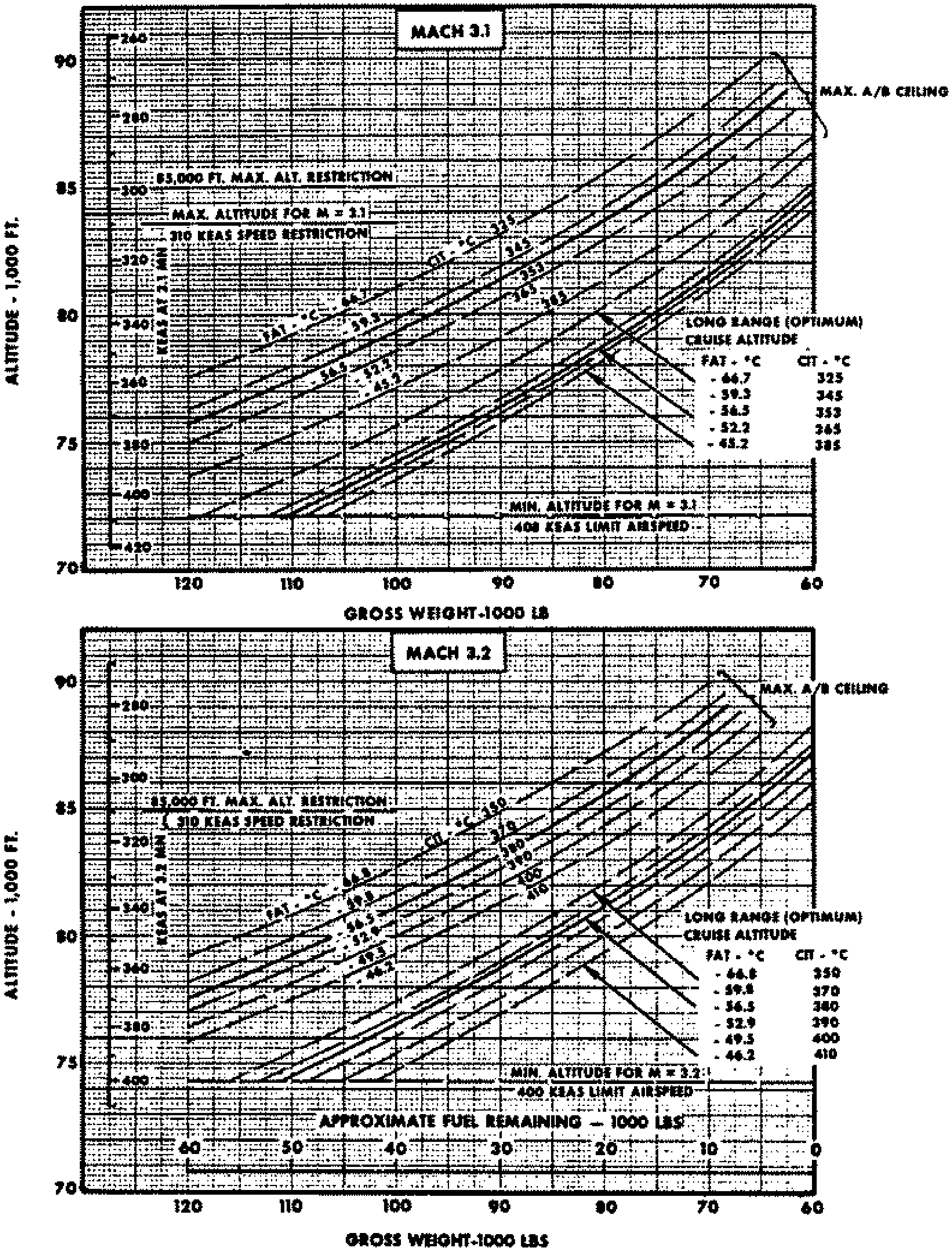
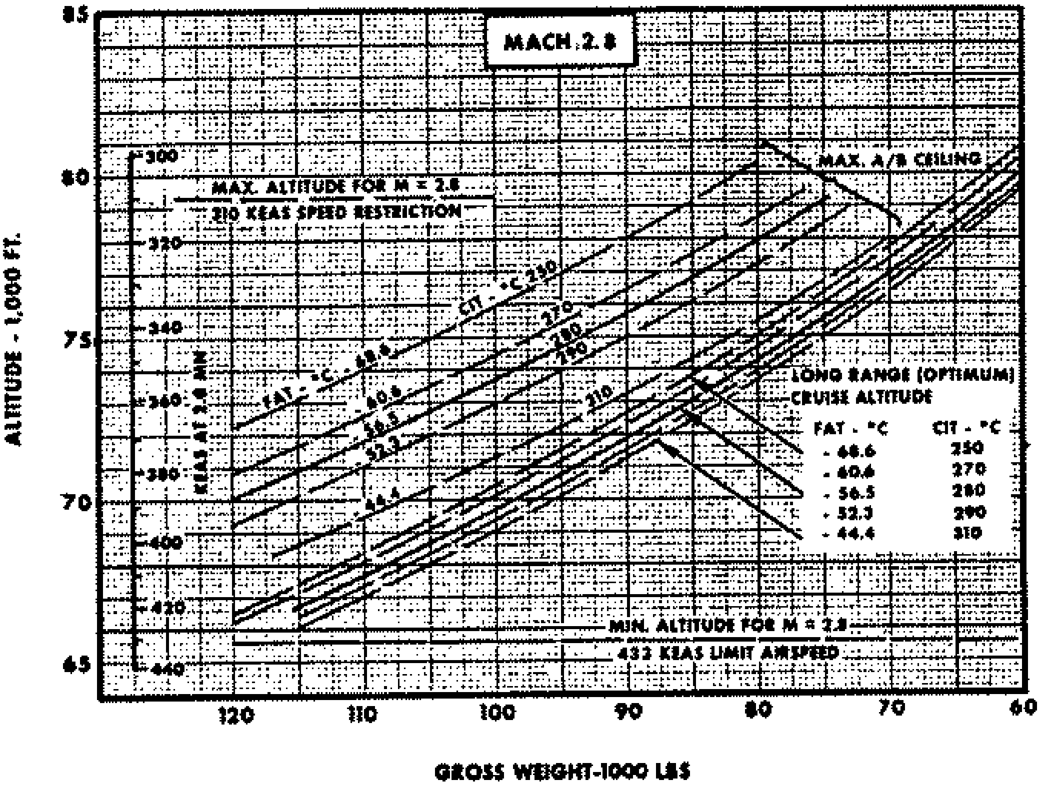


Figure 6-8 (Sheet 1 of 2)

MAXIMUM RANGE AND CEILING ALTITUDES

2° TILTED NOSE   C.G. AT 25% MAC   K ENGINES



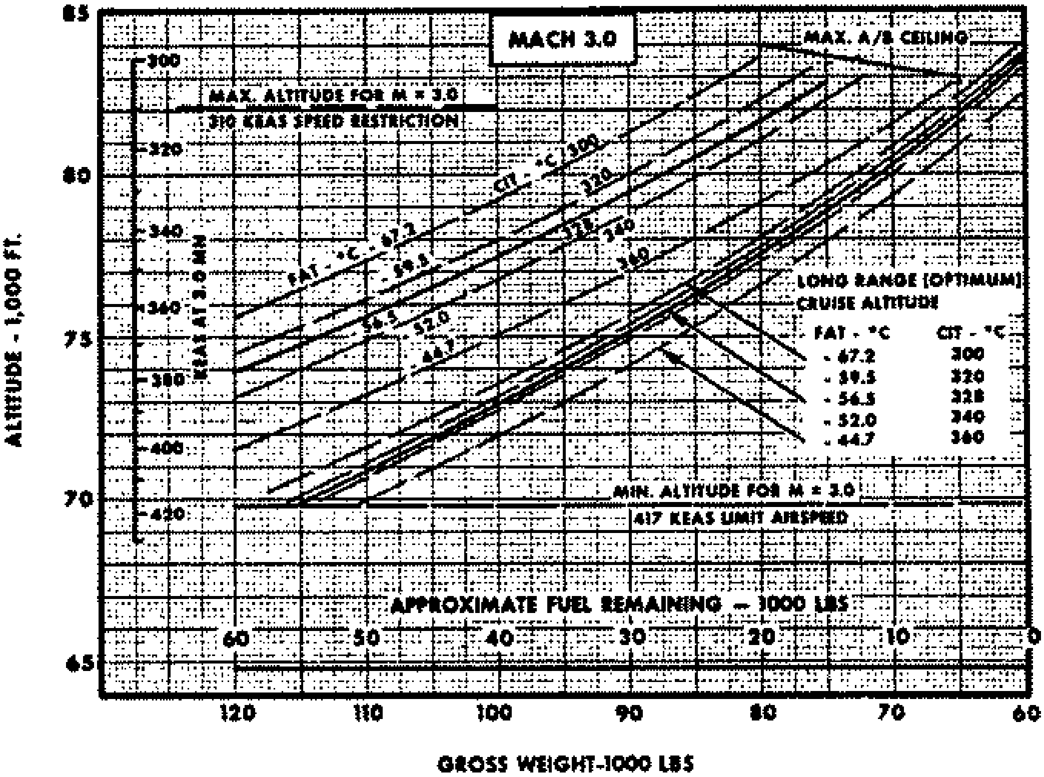


Figure 6-8 (Sheet 2 of 2)

than to maintain constant throttle setting and descend after roll in. It is slightly more economical to allow altitude to decrease while turning, maintaining constant power setting and Mach number during the turn; however, the difference in overall range due to technique is negligible. But there is always a range loss associated with turning, using either technique, of approximately 2.5 miles per 10° of turn when using normal bank angles. It may not be possible to maintain the cruise altitude schedule during steep turns (more than 35°). Whenever the aircraft is power limited in a turn, it is better to lose altitude to maintain Mach than to lose Mach and maintain altitude. An altitude loss below the maximum range cruise schedule should be anticipated for 45° bank-angle turns. A greater loss in altitude may be required for turns on hot days. Refer to Parts V and VI of the Performance Data Appendix.

NOTE

> During descending turns, KEAS must not be allowed to increase above the limit value for the Mach number. Lower bank angles (with increased turn radius) are necessary if the maximum KEAS/minimum altitude schedule can not be maintained by use of power.

Bank angles of up to 45° may be used with the roll autopilot AUTO NAV engaged. Bank angles of 45° are not recommended during climb, except as an operational necessity, due to the reduction in climb performance.

Dihedral Effect At High Speed

A characteristic difference in dihedral effect between the SR-71A and the SR-71B aircraft exists at low angles of attack, above Mach 2.8. The SR-71A aircraft exhibit a normal (positive) dihedral effect; that is, a right yaw produces right roll. Because of the ventral fins, the trainer exhibits a negative dihedral effect; that is, a right yaw produces left roll.

Elevon Positioning In Supersonic Turns

Figure 6-9 illustrates typical elevon positions required to maintain wings level and bank angles of 32° and 42° at speeds above Mach 2.75. Data are provided for airspeeds of 350 and 400 KEAS and c.g. conditions aft of 24% while at 90,000 pounds gross weight. Trends for other airspeeds and weights can be determined from Figure 6-7. Note that nose-up elevon positions are always required when operating within the normal c.g. range. Nose-down positions could occur with c.g. aft of the supersonic limit of 25%. Approximate elevon positions are provided by the pitch trim indicator in the cockpit when the autopilot is engaged and the aircraft is in nonturning 1-g flight. The same indications are obtained when flying manually with the aircraft trimmed to zero stick force (hands-off trim) with wings level. 32° and 42° lines show elevon positions for turns at these bank angles. Note that the control deflection adjustments are relatively small, usually less than one degree. Also note that a reduction in nose-up deflection is typical when near the limit Mach and that nose-down deflection is required if c.g. is aft of the limit. These changes in elevon deflection are not reflected by the pitch trim indication while turning, because of the manner in which trim position indications are affected by operation of the SAS.

Effect of Lagged Yaw Rate (LYR) on Pitch Trim Indications

The pitch trim indicator shows the additive effects of manual trimming and Mach Trim system inputs before autopilot engagement, and the effect of trim inputs due to operation of the autopilot. The trim gage can not reflect control system input signals which result from SAS activity; therefore, the trim gage indication can not represent trimmed elevon positions while in turns. The pitch SAS introduces a nose-down elevon deflection signal to counter the steady state pitch-up rate sensed when the aircraft is in a pull-up or a turn. Without LYR all of the additional trimming necessary to overcome the pitch SAS input in turns must be accomplished by the pitch autopilot or by the pilot through trim and/or control stick adjustments. With the autopilot in control, or when the pilot manually trims out stick force, the pitch trim indicator shows the net requirement needed to overcome the SAS activity and to position the elevons for the desired turn. Figure 6-10 shows typical trim indications for trimmed flight with LYR (roll autopilot on) and without LYR (roll autopilot off) for wings-level and at 32° and 42° bank angles. Flight conditions of weight, Mach, and airspeed are the same as for Figure 6-9.

With LYR, pitch trim values in turns are as much as 2.3 degrees lower than for the same flight conditions without LYR. This occurs because the LYR signal, which is derived from bank angle and the sustained yaw rate sensed by the SAS in a turn, is applied as a nose-up signal to oppose the nose-down signal obtained from the sustained pitch rate sensed by the SAS in a turn. The trim requirements in a turn are reduced by an amount which equals the control signal provided by the LYR, and Figure 6-10 illustrates how the nose-up indicated trim change is smaller than without the LYR. Without LYR the amount of uptrimming required by the pitch autopilot in a turn would increase and could exceed autopilot pitch authority (2.3 degrees δ e) until the slow trim motor could trim out the difference. In some cases with LYR, the indicated trim change from the wings-level condition is almost nil or slightly nose-down. Normal trim positions should reappear on roll out at the conclusion of a turn.

MAXIMUM AFTERBURNER CEILING PROFILE

In the Mach 2.8 to 3.2 range, the maximum afterburner ceiling profile is 4000 to 5000 feet above the altitude schedule for maximum range. The pilot maintains this schedule primarily by small pitch adjustments after the profile is established. The maximum altitude cruise profile (1000 feet lower) is recommended except where maximum altitude is essential.

MAXIMUM ALTITUDE CRUISE PROFILE

The maximum altitude cruise profile is 1000 feet below the maximum afterburner ceiling. Continuous use of maximum afterburner should not be required.

Effect of Mach Decrease

The Mach must not decrease appreciably below the desired cruise Mach. A small decrease in Mach at constant altitude will cause the aircraft to intercept the maximum afterburner ceiling for that speed and become thrust limited. A descent of several thousand feet may be required to reestablish the desired Mach.

Turn Restrictions

NOTE

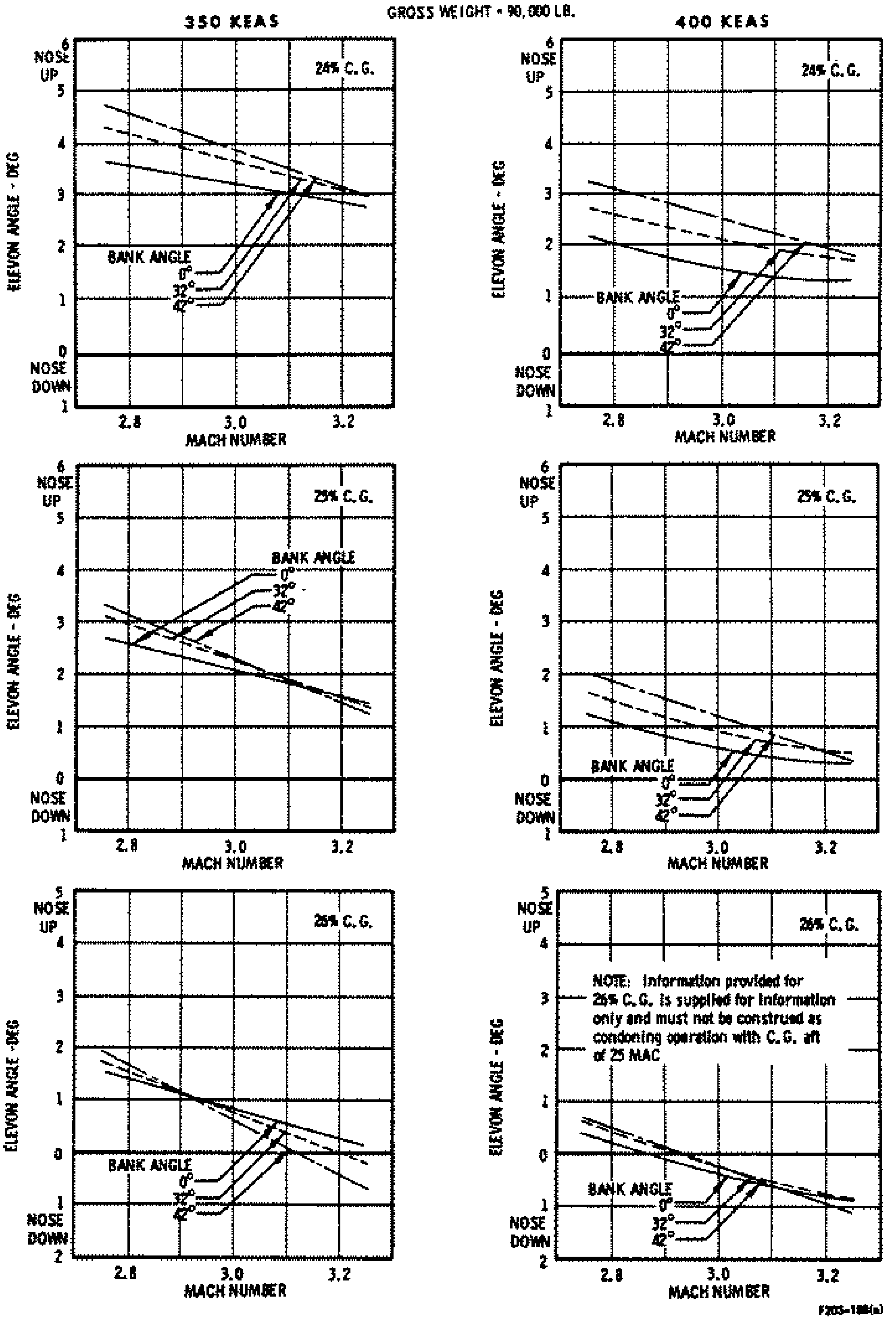
> Turns must be anticipated when flying near maximum altitudes. A descent of approximately 2000 feet should be completed prior to turn entry.

Use of the maximum altitude cruise and maximum afterburning ceiling profiles is restricted to nonturning flight. If 35° bank turns are attempted at these altitude schedules, the angle of attack will exceed 8°. Inlet angle of attack biasing will cause compressor inlet pressure to decrease as much as 2 to 3 psi.

Due allowances must be made for the expected altitude loss if maximum power will not be sufficient to maintain level flight. Refer to Figure 6-8 and the Performance Data Appendix, Parts V and VI.

ELEVON POSITIONS – WINGS LEVEL AND IN TURNS

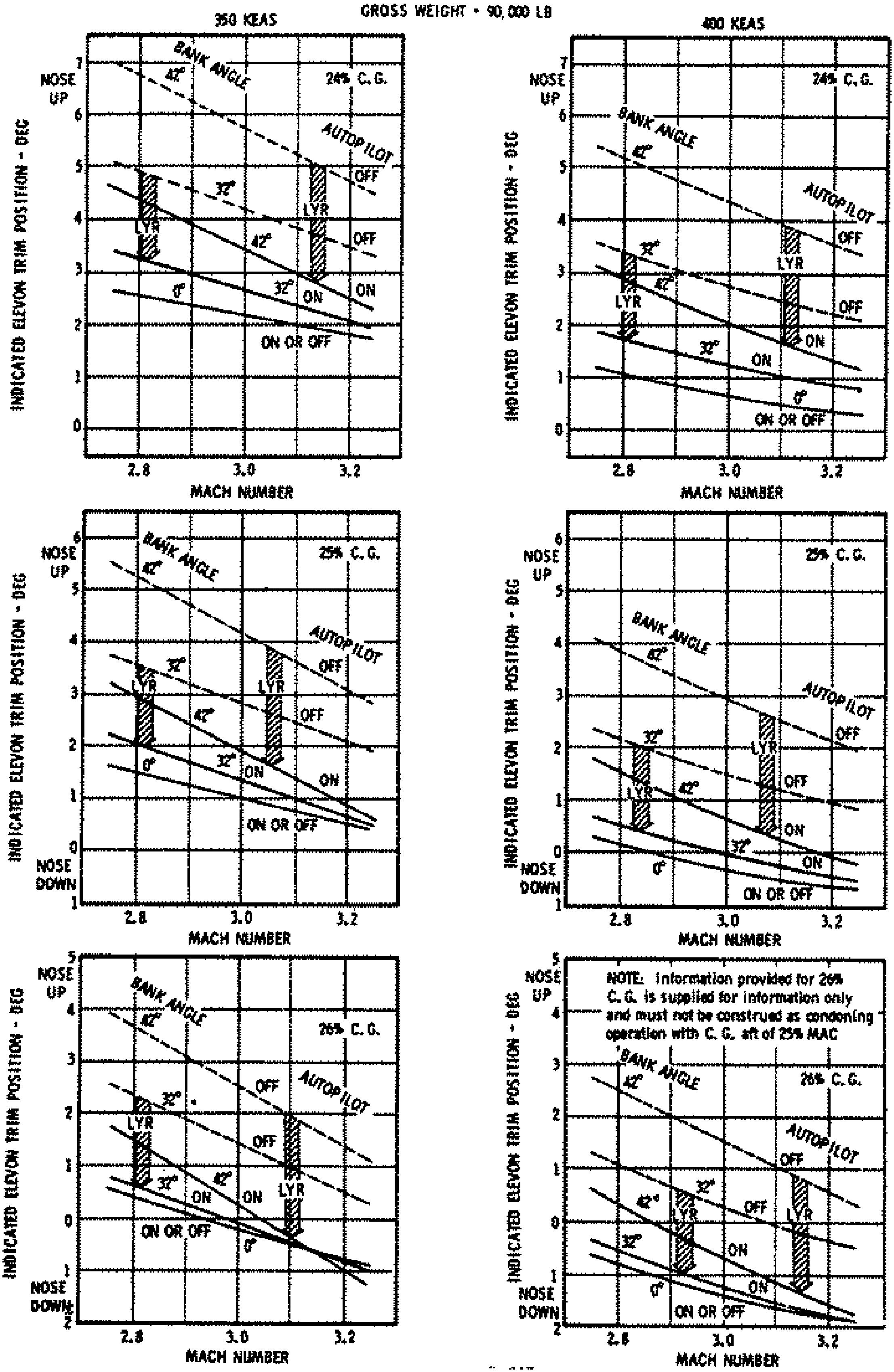
GROSS WEIGHT • 90,000 LB.



NOTE: Information provided for 26% C.G. is supplied for information only and must not be construed as condoning operation with C.G. aft of 25 MAC

Figure 6-9

ELEVON TRIM INDICATION - WITH LYR (ROLL AUTOPILOT ON) AND WITHOUT LYR (ROLL AUTOPILOT OFF)



NOTE: Information provided for 26% C.G. is supplied for information only and must not be construed as condoning operation with C.G. aft of 25% MAC

F203-189(b)

Figure 6-10

When scheduling turns requiring 42° bank angle at speeds above Mach 3.0, the initial weight must be such that the aircraft can stabilize at least 2500 feet above the altitude at which 400 KEAS would be intercepted. Turns at this bank angle must not be planned for such heavy weights that altitude loss would result in exceeding 400 KEAS. In such cases, select a turning radius which requires less bank angle. When planning 42° bank-angle turns at speeds above Mach 3.1, it is also recommended that a distance allowance be included for a descent of 2500 to 3000 feet below the maximum range altitude to be completed and level off accomplished before starting the turn. Maximum thrust may not be sufficient to maintain the maximum range cruise altitude schedule at such high bank angles. The specific range curves in Part V, and the Maximum A/B Constant Mach/Altitude Turn Capability curves in Part VI of the Performance Data Appendix can be used for predicting turning performance and for planning the flight profile required before turn entry.

HIGH ALTITUDE TURN TECHNIQUE

NOTE

> Heavy weight turns at maximum cruise speed should be avoided (if possible) by preflight planning or by turning during the climb, before reaching cruise altitude. Bank-angle turns of 45° are not recommended during climb except as an operational necessity.

Anticipate turns during cruise at the maximum altitude cruise profile or higher, and descend approximately 2000 feet before reaching the turn point. Use minimum A/B, (or a power setting slightly higher, if exhaust nozzle instability is encountered at minimum A/B) when at maximum altitudes. Maintain cruise Mach during the descent, and reset level-flight power before turning. Advance the throttles slowly to maximum afterburner, either after the bank is established or as the turn is entered, considering:

1. A nose-up pitch rate develops during the roll in. Setting maximum afterburner power during the roll in could aggravate control problems if an unstart occurs.
2. A delay in advancing power increases the possibility of altitude loss, but reduces the problem of attitude control if an unstart occurs.

NOTE

> Anticipate a slight increase in indicated TDI Mach as the aircraft rolls into the turn. This does not reflect an actual increase in speed or a need for immediate correction. It is characteristic of the airspeed system at high speed.

Maintain Mach, using pitch attitude adjustment, when turning with maximum afterburner.

WARNING

> Do not make abrupt pitch attitude changes while turning.

Maximum power may also be required to maintain Mach during level turns at the maximum range altitude schedule when using high bank angles. Refer to the Turn Restrictions paragraph for turns above 35° when at the maximum range altitude.

NOTE

> Use of the pitch autopilot with Mach Hold off is recommended for high altitude turns. Use the pitch trim adjustment wheel to control attitude, but do not make abrupt pitch changes.

The pitch autopilot can be used with bank angles up to 45° at all speeds.

DESCENT

Descent characteristics are not unusual except for the variation in flight path angle encountered during the supersonic deceleration. For start of descent, either a constant altitude deceleration is made to 365 KEAS or a constant Mach number descent is made until 350 to 365 KEAS is intercepted. The choice depends on whether airspeed is above or below 350 to 365 KEAS at end of cruise. Then 365 KEAS is maintained. When 350 KEAS is intercepted near Mach 3.2 with military power, the angle of descent is approximately 1°. As speed is reduced and power reduced to near idle thrust, the descent angle increases until over 7° is reached just above Mach 1.0.

AIR REFUELING

Air refueling with the flying boom system of the KC-10 or KC-135 tankers poses no problem of compatability and is normally accomplished between 25,000 and 30,000 feet. The aircraft provides a stable platform with the SAS on. Without afterburning, the aircraft may become power limited at the higher refueling altitudes before a maximum onload can be completed. This requires using either a toboggan technique or completing the refueling with one afterburner on.

Forward visibility in the observation and precontact positions is excellent, but upward, lower, and aft visibility is restricted. Rendezvous is easiest from a slightly low position with the tanker within 60° either side of the nose. The pilot's refueling visibility is optimized by lowering his seat prior to contact. Depth perception through the vee windshield is slightly impaired, and some pilots prefer to use one side of the windshield during contact.

A slight buffet will be felt as the contact position is reached. This is tanker downwash and has no effect on the receiver except for a slight decelerating effect. Acceleration response of the engines is excellent and aircraft drag at refueling speeds produces good deceleration response.

Avoid overcontrolling the engines, while gaining and holding position, due to nonlinearity of throttle position vs engine thrust. A given throttle angle change near military power yields more thrust change than a similar change in the throttle midrange.

The aircraft may become power limited, if the afterburner-on technique is not used, and tobogganing descents of up to 1000 feet per minute can be requested as the military power throttle position is approached. Asymmetric thrust is easily controlled with one afterburner on.

Turbulence encountered while in contact poses no particular problem with SAS operating normally and shallow turns can be made without difficulty. However, if all pitch SAS is inoperative, refueling is not recommended except in an emergency. The aircraft is poorly damped without any pitch SAS, but control can be maintained under favorable conditions with a forward c.g.

After disconnect, movement relative to the tanker should be rearward and slightly downward with wings level. This insures a straight line force separation of the boom from the receptacle.

During night refueling, added caution and effort is required to avoid overshoot, and the tendency toward throttle overcontrol while in contact increases.

The angle of attack is approximately 3° for a lightweight hookup and increases to approximately 6° for full tanks.

APPROACH AND LANDING

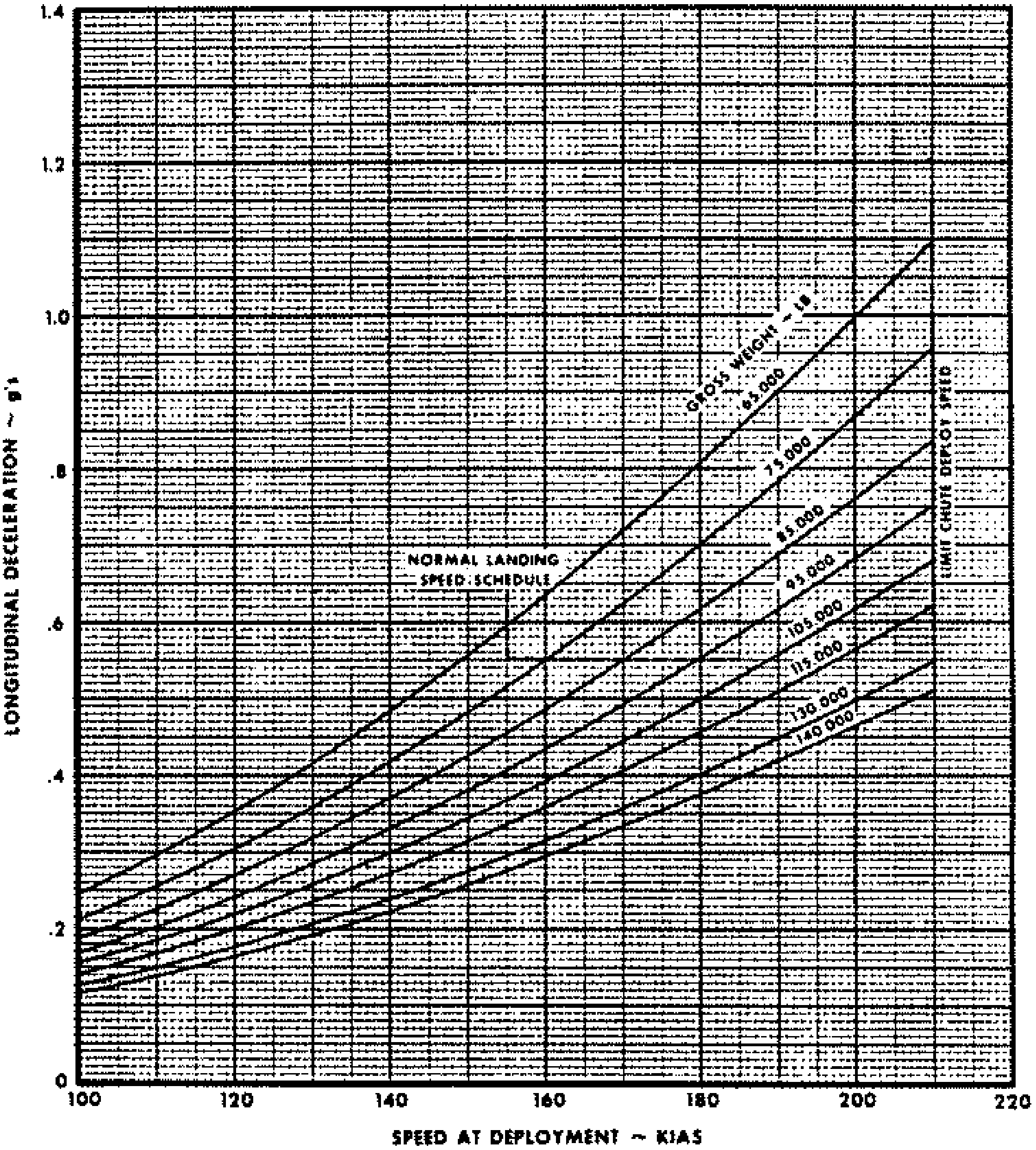
Handling characteristics during approach and landing with SAS operative are good. Short period disturbances are well damped, and available roll rates are adequate. The aircraft can be held off the runway to speeds much lower than recommended landing speed. Normal touchdown angle of attack is from 10° to 12°. There is a risk of damage to the aft fuselage if the touchdown angle of attack exceeds 14°.

Normally the aircraft is flown directly to touchdown rather than attempting to hold just off the runway with subsequent settling at too high an attitude. Prompt chute deployment will result in momentary deceleration loads of about 1/2 g. The chute should not be deployed in the air because of the rapid deceleration and rate of sink that could develop, but it can be actuated before nosewheel contact without any unusual pitching tendencies. During crosswind landings, however, chute deployment should be delayed until the nosewheel is on the runway and steering engaged. Refer to Crosswind Landing, Section II and Landing Gear Limits, Section V.

The initial loads which occur when the drag chute deploys are illustrated by Figure 6-11. Note that approximately 1/2 g initial deceleration can be expected at deployment speeds for normal landings. The initial shock can be much greater during high-speed deployments at light to moderate weights. The load at which the drag chute attachment link is designed to fail is 110,000 pounds.

Practice landings with pitch and/or yaw SAS off are not permitted. The roll SAS may be disengaged prior to simulated and actual single-engine landings. Control during emergency landings with all pitch SAS off is increasingly more difficult if c.g. approaches or exceeds the aft limit.

INITIAL DECELERATION VS CHUTE DEPLOY SPEED



REFERENCE DATE: SEPTEMBER 1972

Figure 6-11

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